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EVALUATION OF CENTRIFIELD SCRUBBER

Joseph D. McCain

Southern Research Institute

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16. ABSTRACT

The report gives results of fractional and overall mass efficiency tests of a Centrifield Scrubber (Entoleter, Inc.). The tests were performed on a full scale scrubber used for controlling particulate emissions from an asphalt plant. Total flue gas particulate mass concentrations were determined at the inlet and outlet of the scrubber by conventional (Method 5) techniques. Inlet and outlet particulate concentrations as functions of size were determined on a mass basis using cascade impactors for sizes from about 0.3 to 5 μm, and on a number basis for sizes smaller than about 1 μm using optical, diffusional and electrical methods. The report includes brief descriptions of the asphalt batching process, the Centrifield Scrubber, measurement methods for determining fractional efficiency, inlet and outlet size distribution data, and fractional efficiencies.

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by

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June 1975

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ABSTRACT

This report presents the results of fractional and overall mass efficiency tests of an Entoleter, Inc., Centrifield Scrubber. The tests were performed on a full scale scrubber used for controlling particulate emissions from an asphalt plant. Total flue gas particulate mass concentrations were determined at the inlet and outlet of the scrubber by conventional (Method 5) techniques. Inlet and outlet particulate concentrations as functions of size were determined on a mass basis using cascade impactors for sizes from about 0.3 μm to 5 μm, and on a number basis for sizes smaller than about 1 μm using optical, diffusional, and electrical methods.

The text of this report includes brief descriptions of the asphalt batching process, the Centrifield Scrubber, the measurement methods, inlet and outlet size distribution data, and fractional efficiencies.

This report was submitted in partial fulfillment of Contract Number 68-02-1480 to Southern Research Institute under the sponsorship of the Environmental Protection Agency. The work reported here was completed January 31, 1975.

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SECTION I
CONCLUSIONS

This evaluation was one of a series of such evaluations being conducted by the Control Systems Laboratory of the Environmental Protection Agency to identify and test novel devices which are capable of high efficiency collection of fine particulates. The test methods used may not be consistent with compliance-type methods, but were state-of-the-art techniques for measuring mass and fractional efficiency using the standard mass train and inertial, electrical, optical and diffusional techniques.

The collection efficiency of the Entoleter Inc., Centrifield Scrubber determined by conventional (Method 5) techniques on a source producing particulate having a mass mean diameter of about 100 μM was 99.50 and 99.73 for two days of testing. Measured fractional efficiencies were about 90% at 0.03 μm, about 50% at 0.05 μm, 20% at 0.1 μm, 50% at 0.5 μm, 90% at 1 μm, and 99.7% at 5 μm. The scrubber energy usage during the tests was approximately 3 JOULES/1000 SCM (80 BTU/1000 SCF) at a pressure drop of 17 cm (6.7 inches) w.c. The Centrifield Scrubber was not found to be substantially different in efficiency from the class of scrubbers known as conventional scrubbers. As shown in Figure 9 of this report, the power consumption for the Centrifield was somewhat lower but not substantially different from that for a well-designed venturi scrubber giving the same particulate collection efficiency.

SECTION II
INTRODUCTION

This report presents results of tests conducted by Southern Research to determine the capability of the Entoleter, Inc., Centrifield Scrubber to collect fine particulates. The goals of the tests were to determine the overall mass efficiency and the fractional efficiency of the scrubber while operating under normal conditions at an asphalt batching plant. Figure 1 is a schematic of the basic asphalt plant and scrubber system showing the inlet and outlet sampling locations. (The scrubber normally operates without a stack and the ducting shown beyond the scrubber exit was added specifically for these tests).

The tests were conducted on a 4 ton Simplicity 200 asphalt plant equipped with a 250 ton/hr capacity H & B dryer, burning No. 2 fuel oil. The plant was operated on an intermittent basis during the test period producing approximately 300 tons of hot mix per day at rates of approximately 150 to 175 tons per hour. The plant used crushed, screened slag obtained from a local steel plant as aggregate. In the batching process, appropriate quantities of roughly sized aggregate are surface dried in the rotary kiln in order to insure that the asphalt will adhere to the aggregate (asphalt will not adhere to a moist surface). After drying, the screened aggregate is weighed in sequence and discharged from hot bins to the weigh hopper in approximately one minute. It is then discharged to the mixer, with the addition of hot asphalt requiring an additional one half minute and then immediately

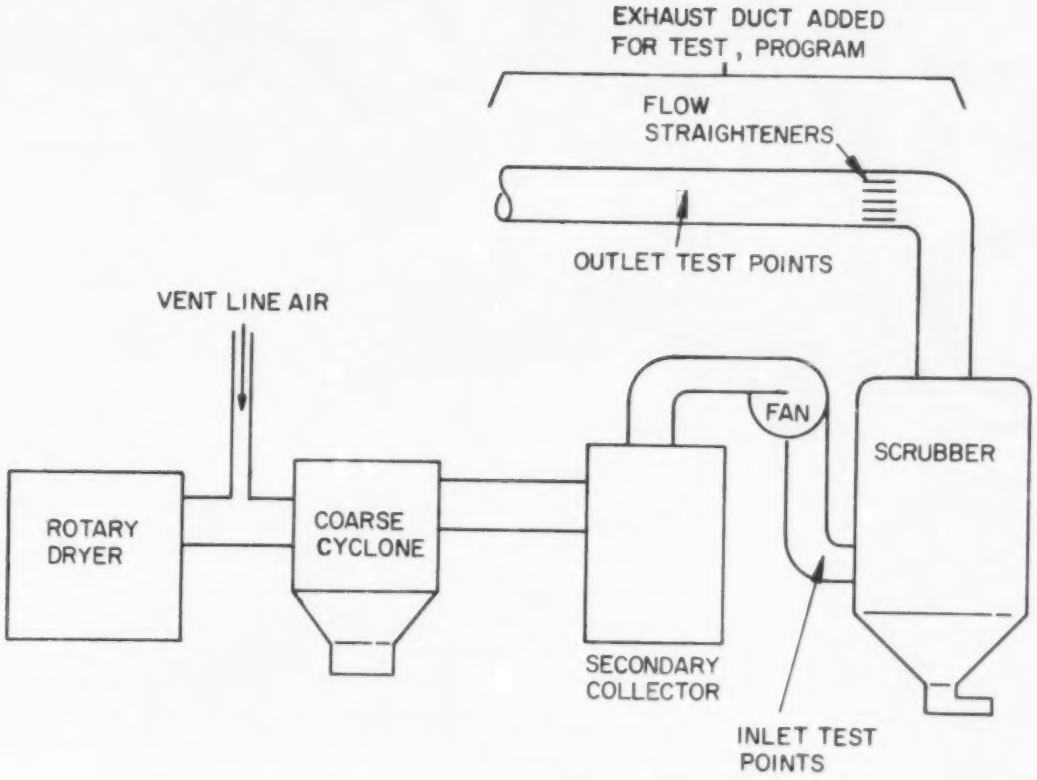

Figure 1. Schematic diagram of the asphalt plant and scrubber layout and the locations of the sampling points used in the tests.

discharged to a truck. The complete sequence including drying requires a total time of about 30 minutes. The particulate emissions from the process are dominated by the drying, screening and mixing portions of the batch operations. Because the test program was carried out during a normally slack season for the industry, some dry runs (runs made without the introduction of the asphalt) of the plant were required in order to obtain sufficient plant operating time for making all the required measurements. Subsequent to the tests, it appeared that the aggregate temperatures were not as closely controlled during the dry runs as during actual operations and that the inlet dust loading to the scrubber was higher during the dry runs than during the normal runs. However, these factors probably had only a small influence on the results of the tests.

The exhaust gases from the plant pass through a coarse cyclone to the fan at a temperature of about 55°C (130°F) and from the fan are forced through the scrubber, emerging at a temperature of about 46°C (115°F). During these tests, the scrubber pressure drop was about 17 cm w.c. (6.7" w.c.) and the system flowrate was about 11.67 M^3/sec (24,720 ACFM). The scrubber water flowrate was approximately 0.53 liters/M^3 (4 gal/1000 CF). A description of the operation of the scrubber is given in Appendix A.

SECTION III
DISCUSSION

A total of five measurement techniques were used during the tests. These were: (1) diffusional techniques using condensation nuclei counters and diffusion batteries for determining concentration and size distribution on a number basis for particles having diameters less than approximately 0.2 μm, (2) optical techniques to determine concentrations and size distribution for particles having diameters between approximately 0.3 μm and 1.5 μm, (3) electrical methods to determine concentrations and size distribution on a number basis over the size range from 0.01 μm to 1 μm, (4) inertial techniques using cascade impactors for determining concentrations and size distributions on a mass basis for particles having diameters between approximately 0.25 μm and 5 μm, and (5) standard mass train measurements for determining total inlet and outlet mass loadings.

The useful concentration ranges of the optical counter, electrical counter (Thermosystems Model 3030 Electrical Aerosol Analyzer), and the condensation nuclei counters are such that extensive dilution of the gas streams being sampled was required. Dilution factors of about 50:1 were used for both inlet and outlet measurements. In order to insure that condensation effects were minimal, and that the particles were dry as measured, the diluent air was dried and filtered, and diffusional driers were utilized in the lines carrying the diluted samples to the various instruments.

Because only one set of optical and diffusional sizing equipment was available, it was not possible to obtain simultaneous inlet and outlet data with these methods. The

system was first installed at the inlet sampling location, and all the inlet data were obtained. Subsequently, the equipment was moved to the outlet and the necessary outlet data were obtained. For the purposes of calculating the efficiency of the scrubber, the assumption was made that the process was sufficiently repetitive that the inlet data, as obtained above, were a valid representation of that which would have been obtained during the time the outlet measurements were made. Accuracy in the measurements was limited by process variations and the efficiencies derived from these data are somewhat uncertain. However, the trends in the fractional efficiencies derived from the data are probably real and the fractions of the influent material that penetrate the scrubber are believed to be generally correct to within a factor of two.

The optical data are presented on the basis of equivalent polystyrene latex sizes and the indicated sizes can differ from the true sizes by factors as large as two to three. Data obtained using this method were primarily intended as a means of real time monitoring of process changes, but also serve as rough checks on the data obtained with the cascade impactors.

The tests took place on the dates of October 14 through October 23, with October 14 and 15th primarily used for instrumentation setup, checkout, and preliminary measurements. Because of difficulties in erecting the outlet ducting, no outlet data was obtained until October 21. The scrubber conditions were checked by a representative of the manufacturer prior to the start of the tests.

Figures 2 and 3 show records made at the scrubber inlet and outlet using the optical and diffusional systems. Figure 2 shows inlet data obtained during a dry run on October 18, while Figure 3 shows outlet data obtained during an actual batching operation.

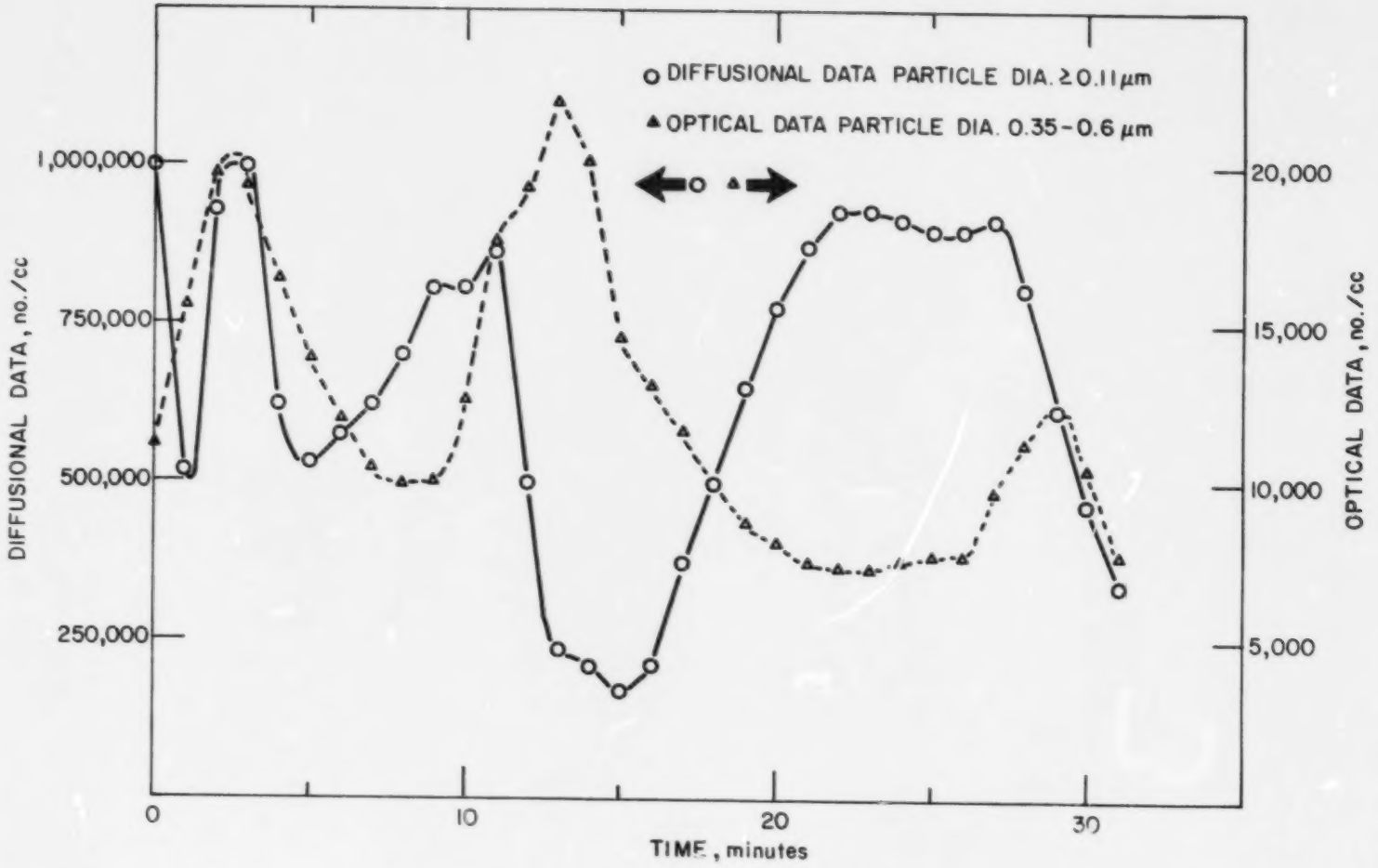

Figure 2. Typical inlet data segment obtained with optical and diffusional methods.

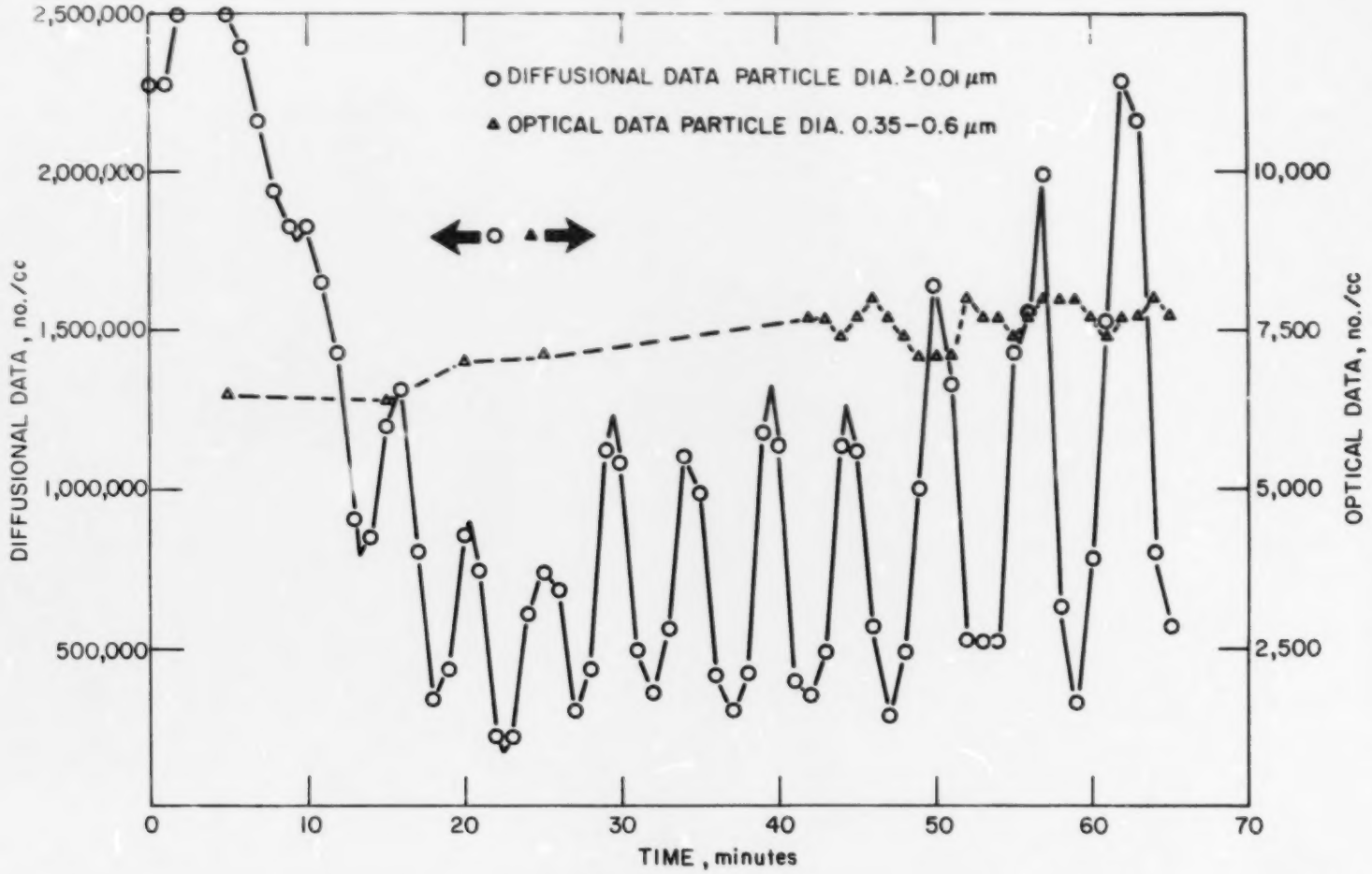

Figure 3. Typical outlet data segment as obtained with optical and diffusional methods.

It is evident from Figures 2 and 3 that large variations in the particulate concentration and size distribution occurred. The major swings in the condensation nuclei counter (diffusional) data appear to result from variations in the fuel feed rate caused by the servo system used to control the surface temperature of the dried aggregate. Records of the kiln exit gas temperature show swings having patterns like those shown in the condensation nuclei counter data. The variations in the optical counter data probably result for the most part from variations in the aggregate feed rate to the kiln. The accuracy of the fractional efficiency results were thus limited by the degree to which appropriate inlet and outlet time averages could be obtained.

Figure 4 shows typical averaged inlet and outlet size distributions as obtained by optical, electrical, and diffusional methods over approximately one batch. Figure 5 shows the fractional efficiencies calculated from these data together with results from the impactor measurements. In Figure 5, the impactor data is presented using particle diameters based on particle densities of 2.5 g/cm^3. Because the diffusional and electrical data sets were not usually obtained simultaneously, the averages of the data sets obtained with each method were not the same. The difference was especially large at the outlet of the scrubber. Thus, the fractional efficiencies calculated from the two data sets do not precisely agree although both show the same general trends. The differences in the calculated fractional efficiencies indicate, to some extent, the uncertainties introduced by process variations.

Inertial sizing was accomplished using Brink Cascade Impactors for inlet measurements and Andersen Impactors for outlet measurements. Sampling was done at near isokinetic rates. Errors due to deviations from isokinetic sampling should be of little consequence for particles having aerodynamic diameters smaller than 5 μm. The outlet impactor

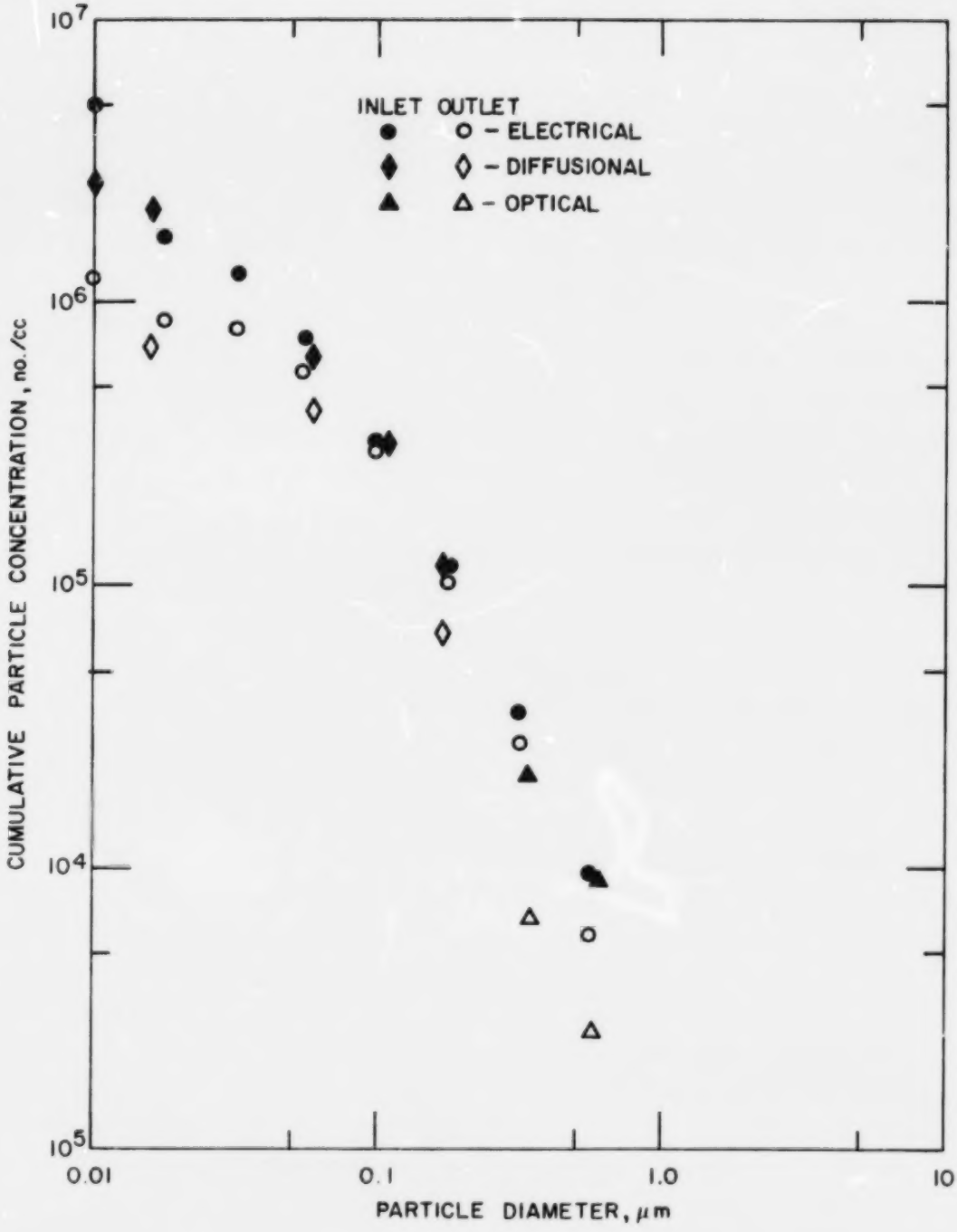

Figure 4. Inlet and outlet size distributions as obtained with optical, diffusional, and electrical techniques.

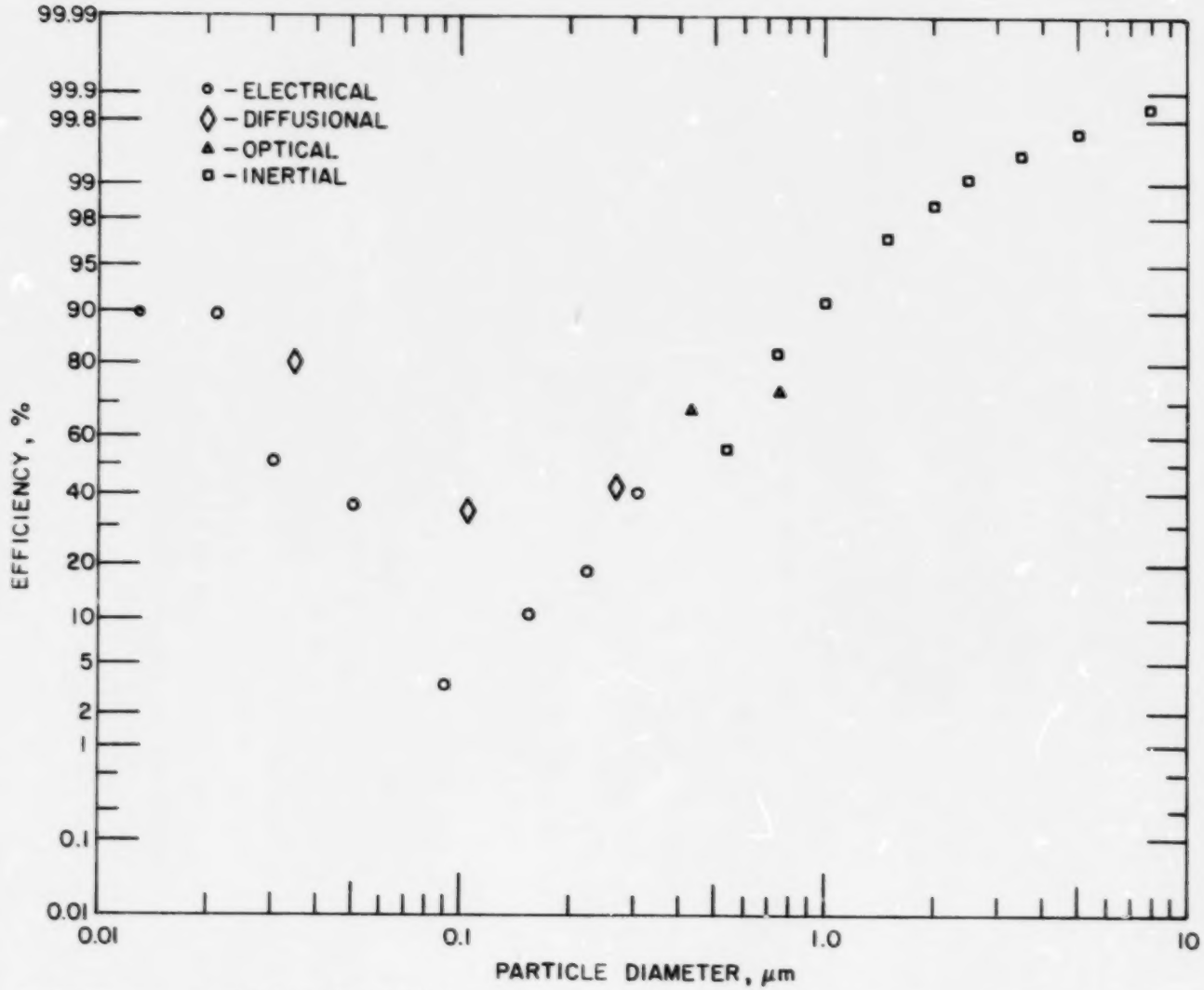

Figure 5. Fractional efficiencies as determined by the four methods used in the test program. The particle sizes shown for the impactor data are Stoke's Diameters based on a particle density of 2.5 grams/cm^3.

samples were obtained with the impactors heated to about 22°C (40°F) above flue gas temperature to insure that no condensation took place within the impactor. Such condensation might cause operational difficulties or lead to incorrect sizing. Liquid droplets, mist and fog were present in the outlet duct and insufficient drying time was available in the inlet nozzles of the impactors for complete evaporation of large droplets, resulting in substantial losses of large droplets in the inlet nozzles. Material contained in these droplets was not included in the impactor data reported here.

Because of the wide disparity in the inlet and outlet mass loadings (inlet ∿ 20,000-69,000 mg/DSCM (9-30 grains/DSCF)) and outlet ∿ 110-230 mg/DSCM (.05-.1 grains/DSCF), complete simultaneity in the inlet and outlet sampling was not possible. Outlet samples were generally of about 45 minutes duration while inlet samples were of about 5 minutes duration. Because the inlet sampling could not correspond directly with the outlet sampling, an average inlet mass loading for one batch was synthesized for each size interval covered by the inlet impaction stages from a total of 14 runs.

The sizes reported here for the inertial data are given in two forms, "aerodynamic" and "physical", or Stoke's, diameters. The "physical" diameters are based on an assumed particle density of 2.5 g/cm^3. If the true particle densities are lower than this value, the sizes as given should be increased by a factor equal to the square root of ratio of the assumed density to true density. Aerodynamic diameters are diameters based on a particle density of 1 g/cm^3. The impactor data are summarized in Tables I and II. Figure 6 shows averaged inlet and outlet mass size distributions on a cumulative percentage versus aerodynamic diameter basis. Figure 7 shows the same size distributions

TABLE I

Inlet Mass Loadings By Size Interval From Brink Impactor Data

	Date	Start	Duration (Min.)	Dia., μm ρ = 2.3	Loading (mg/DSCM)								
					>9.4	6.7-9.4	3.80-6.7	2.25-3.80	1.57-2.25	.83-1.57	.60-.83	.34-.60	<.34
1	10/15		3.0		28800	634	396	211	96.3	81.5	37.0	25.9	37.0
2	10/15		3.0		55800	2720	1940	908	307	222	55.6	25.9	81.5
3	10/16		3.0		34300	2680	2300	750	342	223	66.9	3.71	29.7
4	10/16	3:30	1.5		15800	430	219	106	30.2	15.1	22.6	22.6	98.0
5	10/17	9:40	3.0		47300	2240	1560	635	177	97.8	22.6	18.8	7.52
6	10/18	10:30	3.0		68700	535	1670	1530	428	210	1440	40.6	48.0
7	10/21	11:45	3.5		58100	970	1220	717	525	337	84.2	47.1	90.9
8	10/21	3:40	3.3		95400	3060	2660	1280	404	261	78.6	64.3	60.7
9	10/22	11:30	3.0		65900	1790	1410	1160	279	185	66.8	31.4	70.7
10	10/22	2:00	3.0		43000	1330	1980	1130	2150	181	55.0	31.4	102
11	10/23	9:12	3.0		117000	2930	4110	2740	692	369	145	130	122
12	10/23	9:20	3.0		17600	2140	2180	1190	507	306	74.7	82.5	134
13	10/23	12:30	3.0		1890	1250	1050	695	228	177	55.0	43.2	35.4
14	10/23	12:40	3.0		49800	2240	2970	1170	460	240	62.9	31.4	11.8
				Dia., μm ρ = 1.0	>14.2	10.1-14.2	5.8-10	3.4-5.8	2.4-3.4	1.3-2.4	.94-1.3	.56-.94	<.56

TABLE II

Outlet Mass Loadings By Size Interval From Andersen Impactor Data

	Date	Start	Duration (Min.)	Dia., μm ρ = 2.5	Loading (mg/DSCM) >9.6	6.7-9.6	4.2-6.7	2.9-4.2	1.9-2.9	.88-1.9	.53-.88	.38-.53	<.38
1	10/21	11:33	40		1.50	2.23	1.67	1.88	1.31	12.2	17.1	11.1	6.42
2	10/21	11:40	40		4.12	3.30	1.50	2.72	3.25	15.1	21.3	14.9	11.90
3	10/21	3:28	30		2.41	2.57	4.59	3.50	5.75	22.1	38.3	31.3	27.9
4	10/22	10:13	20		2.82	2.03	2.47	2.56	5.91	23.7	31.9	19.0	10.8
5	10/22	11:25	21		2.14	1.68	1.34	0.50	2.18	4.20	7.98	3.28	1.26
6	10/22	1:22	15		2.54	2.77	2.89	2.42	3.93	14.3	23.9	11.3	4.96
7	10/22	3:43	20		3.78	4.11	17.7	18.7	11.5	12.7	9.31	8.14	4.45
8	10/23	9:12	20		7.69	4.30	5.99	5.88	15.8	18.2	33.7	25.1	10.7
9	10/23	9:12	20		6.48	5.96	7.30	5.96	13.3	20.7	30.0	21.4	10.8
10	10/23	12:36	20		7.25	3.29	5.51	3.19	6.19	12.8	21.1	11.9	8.22
11	10/23	12:38	20		6.55	3.28	4.52	4.41	5.31	11.7	19.2	12.8	5.99
				Dia., μm ρ = 1.0	>14.5	10.2-14.5	6.3-10.2	4.4-6.3	2.9-4.4	1.37-2.9	.84-1.37	.62-.84	<.62

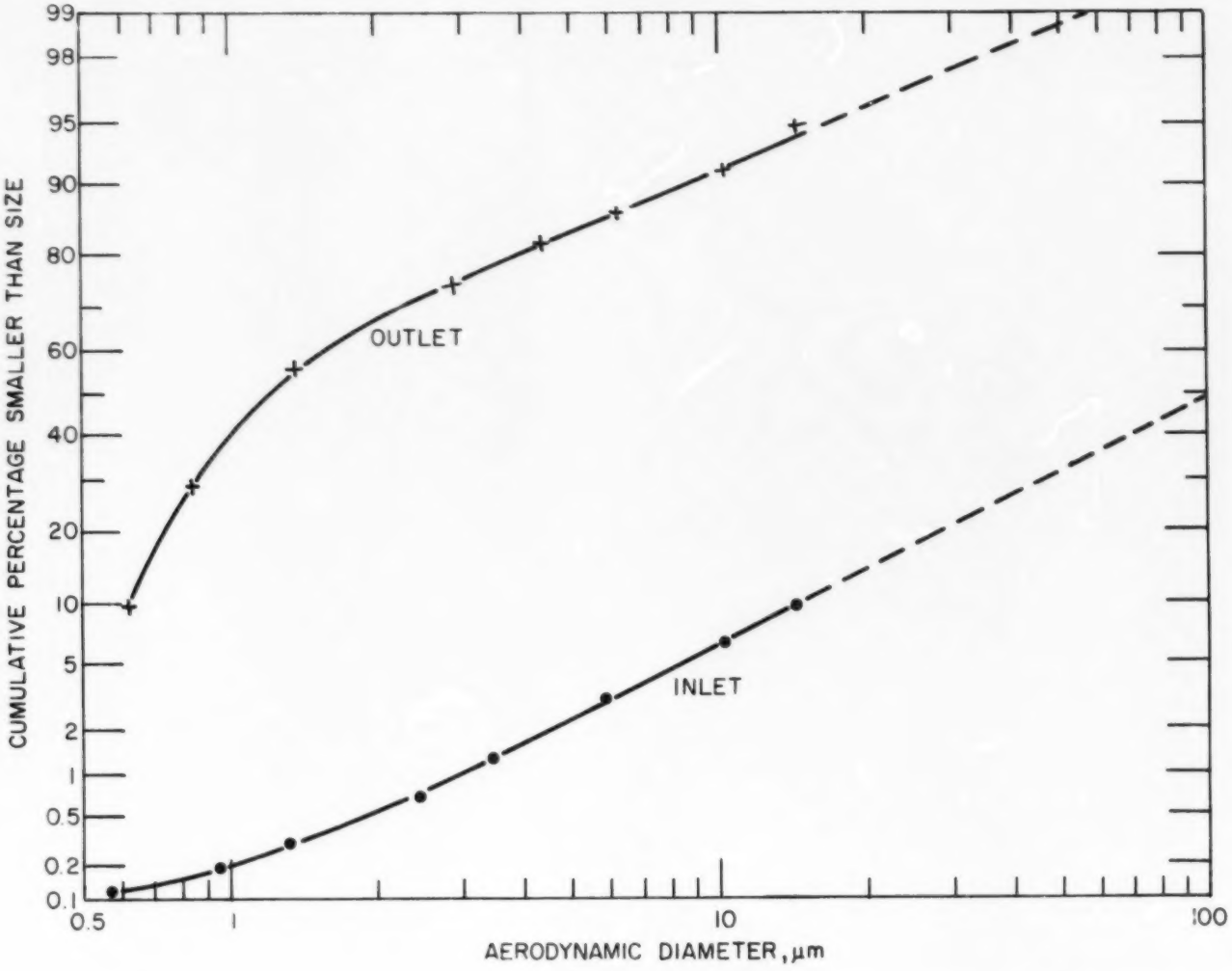

Figure 6. Entoleter Scrubber inlet and outlet size distributions on a cumulative percentage by weight basis. Data obtained with Cascade Impactors.

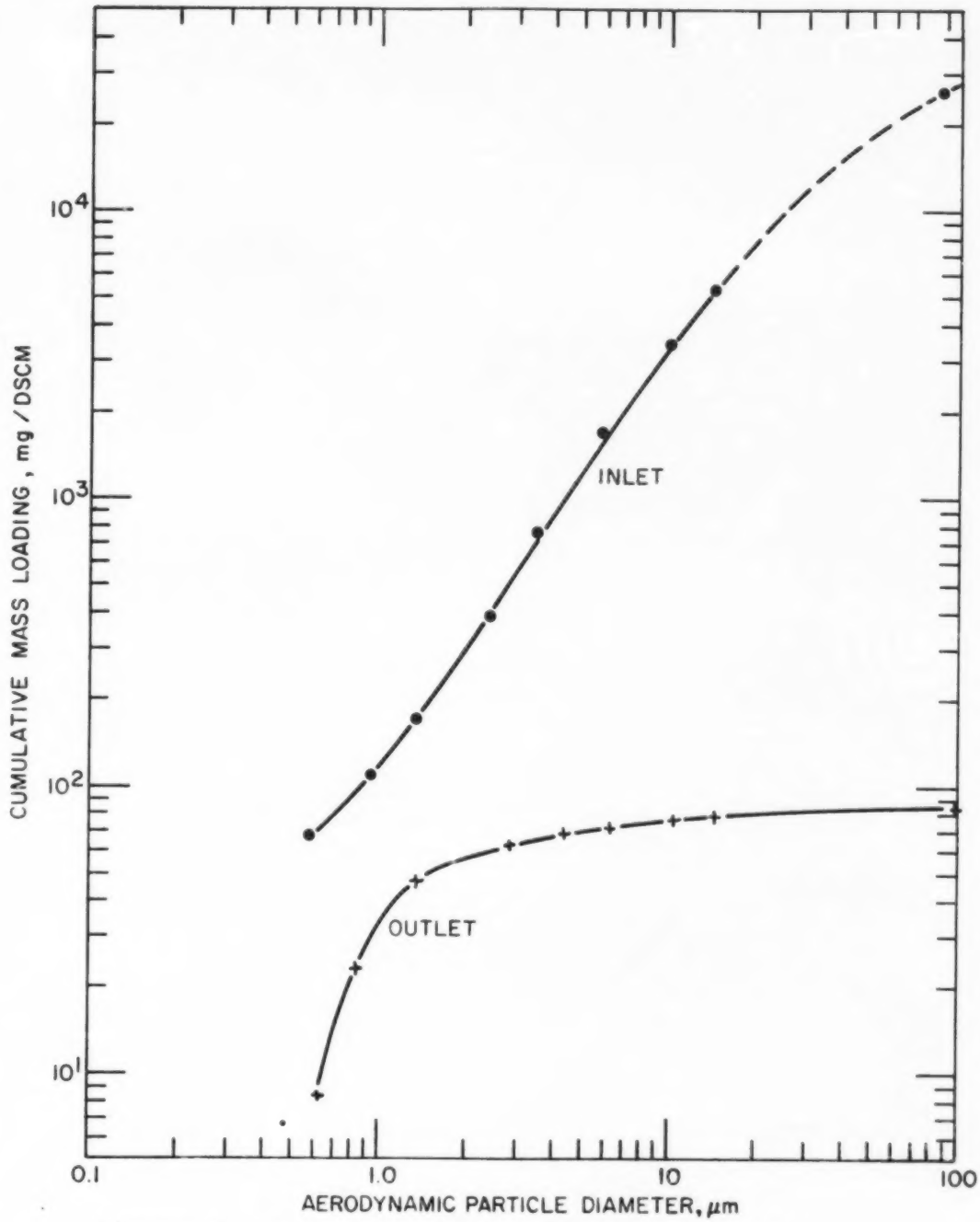

Figure 7. Entoleter Scrubber inlet and outlet size distributions on a cumulative mass loading basis.

on a cumulative mass concentration basis. The fractional efficiencies as calculated from these data are shown in Figure 8 on an aerodynamic diameter basis and were shown in Figure 5 on a physical basis.

Mass train measurements were obtained by Guardian Systems, Inc., Anniston, Alabama, under subcontract to Southern Research Institute on October 21 and 22, and the results of these measurements are shown in Table III. The overall efficiencies, by mass, based on these results are included in Table III. Runs 1, and 3 were dry runs of the asphalt plant that were made solely to permit sampling to take place while runs 2, and 4 were actual batching operations. From the differences in inlet particulate loadings under the two conditions, it would appear that the dry runs may not well represent typical plant operations, although they were deemed to be satisfactory for the purposes of characterizing the performance of the scrubber. Records of the aggregate temperatures leaving the rotary dryer also showed pronounced differences between the dry runs and the actual runs. Both the inlet and outlet particulate loadings during all these tests were substantially higher than they were during previous tests on the same scrubber performed by another group. This may have been due in part or wholly to the fact that subsequent to the previous tests an American Air Filter Multiclone that had preceded the Entoleter Scrubber was removed from the system.

In addition to measuring particulate collection efficiencies, SO_x collection efficiencies were determined by using H_2O_2 in the impingers following the mass train to react with any SO_2 present to form H_2SO_4. Subsequent H_2SO_4 concentration determinations were made on the impinger water samples from which the SO_x collection efficiencies

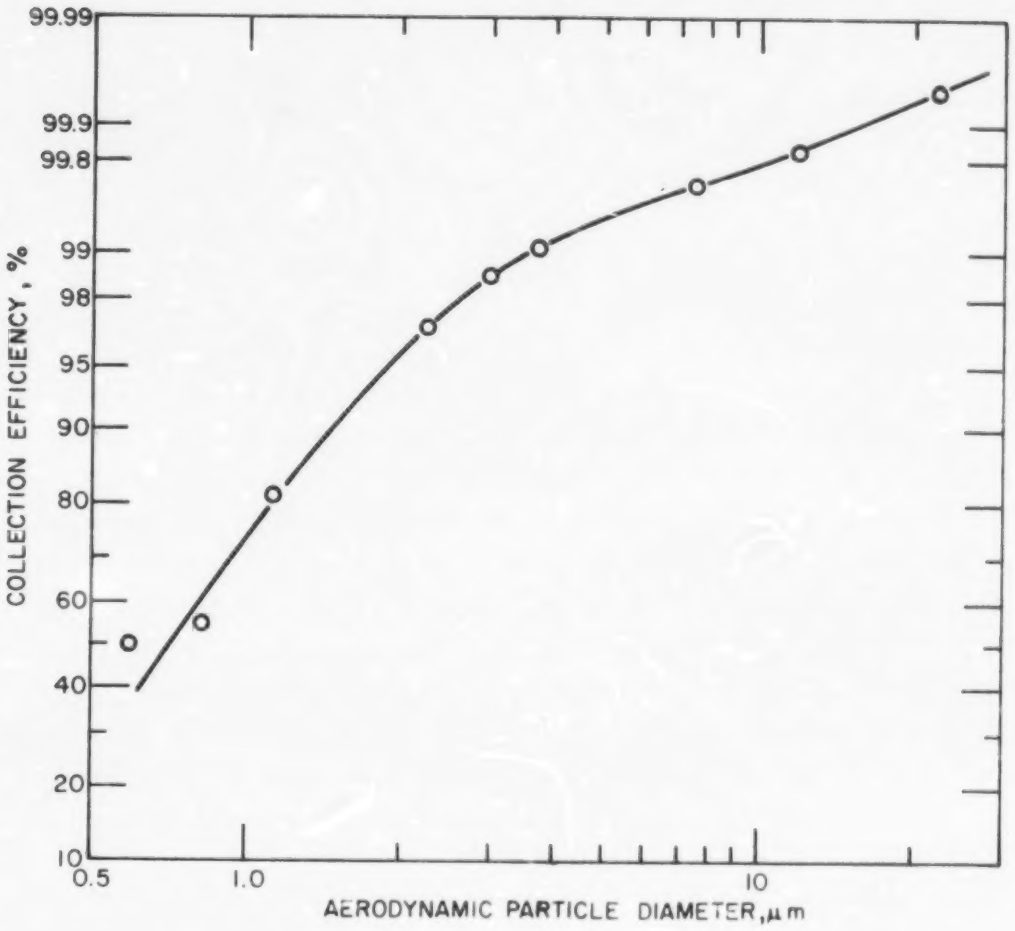

Figure 8. Fractional efficiencies of the Entoleter Centrifield Scrubber as determined from cascade impactor data.

TABLE III

METHOD FIVE RESULTS

Inlet

Run Number	1	2	3	4
Date	10/21	10/21	10/22	10/22
Duration (Min.)	52	15	40	40
Temperature ^{o}R	602	601	582	579
Temperature ^{o}K	334	334	323	321
Grains/DSCF	8.88	25.82	14.66	28.53
Grams/DSCM	20.3	59.2	33.6	65.3

Outlet

Run Number	1	2	3	4
Date	10/21	10/21	10/22	10/22
Duration (Min.)	100	50	90	90
Temperature ^{o}R	575	583	576	574
Temperature ^{o}K	319	324	320	318
Grains/DSCF	.052	.120	.071	.045
Grams/DSCM	.119	.275	.163	.103
Collection Efficiency	99.41	99.54	99.52	99.84

were calculated. These were 84%, 68%, and 88% for the three tests runs for which such data were obtained.

The performance obtained with the Centrifield scrubber during these tests can be compared with the expected performance figures for other types of scrubbers using the "cut diameter" method described by Calvert (1974) J APCA, 24:929. This method is based on the idea that the most significant single parameter to define both the difficulty of separating particles from gas and the performance of a scrubber is the particle diameter for which the collection efficiency is 0.5 (50%). Figure 9 is adapted from one presented by Calvert (op cit). It shows control device aerodynamic cut diameter graphed against power per unit flow rate (hp/1000 acfm). Also shown is the equivalent air pressure drop if all the power went into moving the volume of air through a flow resistance. The lines shown are theoretical and not experimental. Lines 1a and 1b are for sieve plate type scrubbers with froth density F=0.4, hole diameters d_h=0.5 and 0.3 cm respectively. Line 3 is for impingement plates and line 4 is for a packed column from 1 to 3 M high and packing of nominal 2.5 cm diameter. Line 2a for venturi scrubbers (f=0.25) represents the performance of venturi scrubbers in collecting hydrophobic particles while line 2b (f=0.5) represents the same class of scrubbers in collecting hydrophyllic particles. From the Centrifield scrubber operating conditions given in Section II of this report and the measured performance data as given in Section III the Centrifield scrubber during these tests operated a power of 1.68 KW/CM/sec (1.16 H.P./1000 ACFM) and produced an aerodynamic cut diameter of about 0.7 μm. The location of these performance figures is shown as a cross (+) in Figure 9.

Appendices are included which contain summaries of the plant operation and production data and a manufacturer's description of the scrubber operating principles.

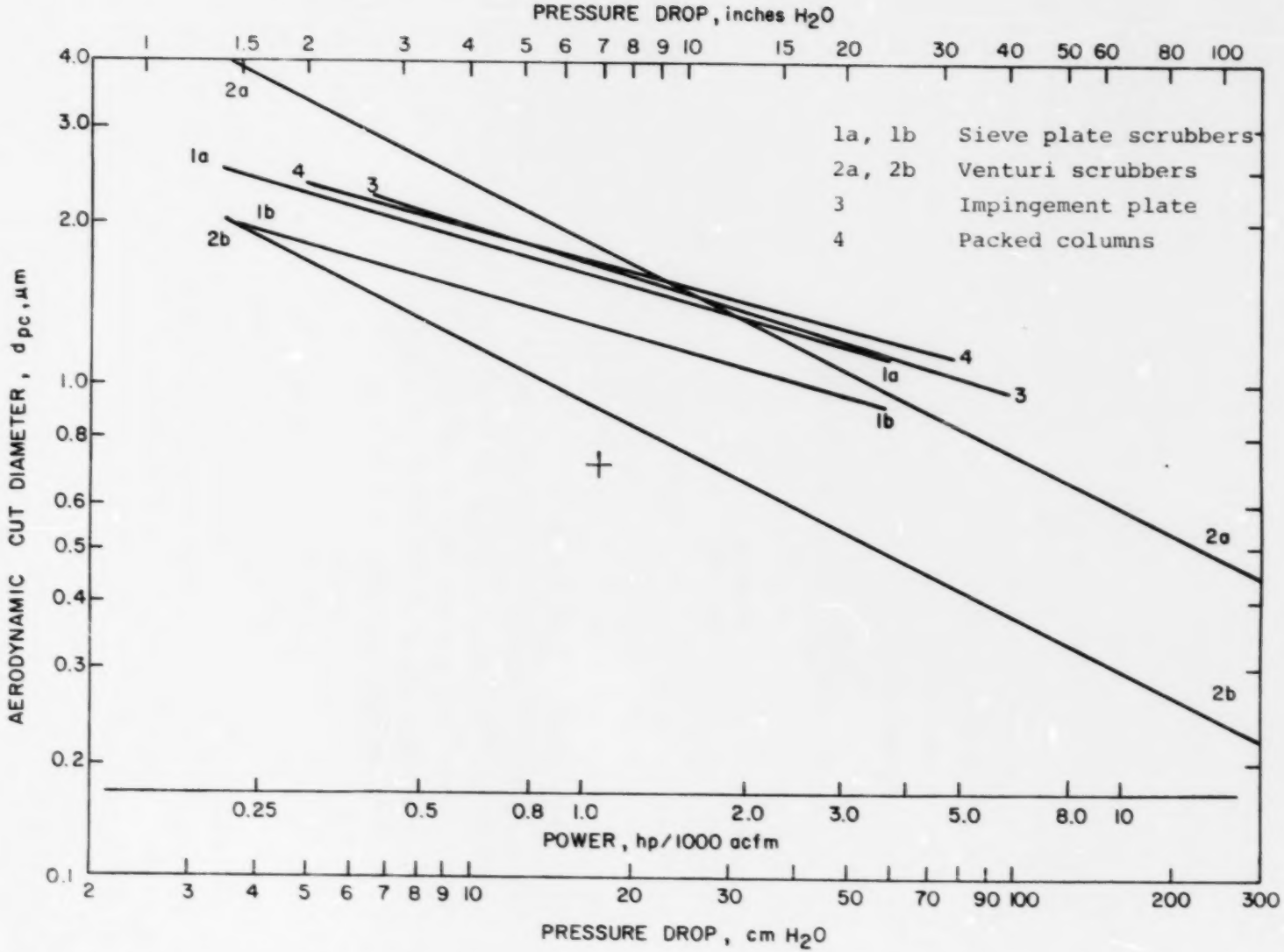

Figure 9. Representative cut diameters as a function of pressure drop (power per unit flow) for several scrubber types, after Calvert, (1974) J. APCA, 24:929. The performance of the Entoleter Centrifield scrubber during these tests is represented by the cross (+).

APPENDIX A

MANUFACTURER'S DESCRIPTION OF THE SCRUBBER OPERATIONS

Modern, high-efficiency wet scrubbers for the removal of entrained particulates from industrial exhaust gases depend, almost without exception, on spray contact for particle interception. The atomization and acceleration of the scrubbing liquid into contacting zone can be performed by a wide variety of mechanical arrangements. A new high-performance contactor, the centripetal vortex contactor, is now available.

The centripetal vortex principle is illustrated in Figure A1. For any point on radius r_c and tangential gas velocity v_t, a particle may exist whose terminal velocity toward the vortex periphery exactly equals radial gas velocity v_r. If the particles consist of liquid droplets, and the peripheral inlet vanes are of the proper configuration, the vortex selectively develops a specific droplet diameter distribution within the rotating field, as determined by r_c, v_i, and ϕ. The average droplet diameter created by a field of this type is substantially smaller than that created by a conventional spray contactor at the same energy level. Droplet diameter is one of the basic parameters of spray contactor efficiency.

Gas scrubber performance is most conveniently described by the relationship: $N_t = aP^Y$, where $N_t = \log_e [1/(1-\text{collection efficiency})]$ and P = energy input per unit of gas treated. For a given dispersoid, an improvement in gas scrubber design results in an increase in a. The centripetal vortex principle should theoretically increase a by approximately 20% over a conventional contactor.

The droplet formation within a spray contactor is inherently in co-current flow in respect to the gas stream, which limits its gas absorption efficiency to a maximum of one theoretical plate per stage. Nevertheless, spray

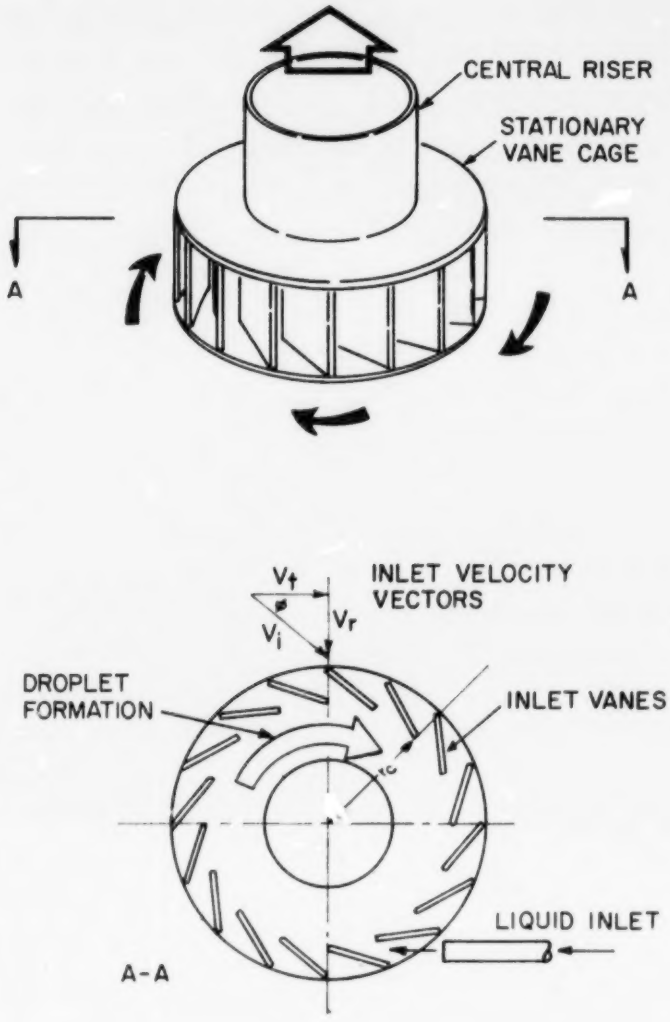

Figure A1. Centripetal vortex balances gas velocity against centrifugal force.

contactors, in single or multiple stage arrangements, are often the only feasible mass transfer device, expecially in applications where insoluble particulate is present, or where the product of the absorption process tends to foul conventional packing and sieve plates. Mass transfer efficiency in a spray contactor is, as would be expected, a function of L/G ratio and specific droplet surface area. Since specific surface area varies inversely with droplet diameter, it is reasonable to expect that the centripetal vortex, with its unusually small equilibrium droplet diameter, would exhibit superior mass transfer capabilities.

APPENDIX B

PLANT PRODUCTION DATA

Base Aggregate Diameters $\leq$ 1 inch

Top Aggregate Diameters $\leq$ ¼ inch

Sheet Aggregate Diameters $\leq$ 1/8 inch

PLANT PRODUCTIONS IN TONS

	10-16	10-17	10-18	10-21	10-22	10-23
Base	57	13	133	366	75	
Top	134	140	112	10	464	127
Sheet	0	0	0	0	29	